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Discussion of
IMPROVING THE LOAD CARRYING CAPACITIES OF SUBGRADES

by Charles M. Noble
(Proc. Paper 505)

EUGENE Y. HUANG,[1] A. M. ASCE.—The importance of the role played by the subgrade of a highway or an airport pavement cannot be overemphasized. It is the element of a pavement structure which actually supports the weight of traffic whether the superimposed pavement is rigid or flexible. It is closely associated with the structure of the pavement. The integrity of a pavement cannot be preserved if the subgrade is insufficient to support traffic loads without serious deformation occurring in either the pavement or subgrade. Many of the defects to which a pavement is susceptible may be attributed, directly or indirectly, to the subgrade on which the pavement is built. It is important, therefore, that appropriate attention be given to the subgrade in the design and construction of pavement structures. Mr. Noble's paper reviewing the recent trends and methods of improving the load-carrying capacities of subgrades contains a great deal of useful information and should be of interest to those who are engaged in road or airport construction work when confronted with the problem of rapid, though not unanticipated, increase in the volume of traffic accompanied by increased wheel loads and increased percentages of heavy loads.

Recognizing the fact that the subgrade must withstand stresses due to traffic, it is obvious, in deciding upon the type and thickness of pavement to construct on any particular soil, that primary consideration should be given to the strength of the stressed layer of soil under local conditions and to the weight and intensity of traffic using the paved structure. The basic objective of an engineer is to provide a structure having a pavement of sufficient thickness and strength to distribute the applied loads to the supporting subgrade without exceeding its bearing capacity. There are two fundamental approaches to this problem. The first assumes that the supporting subgrade in its natural environment must be accepted as it exists and the item of control is taken as the type and thickness of the pavement. An extreme of this idea is the questionable concept mentioned by Mr. Noble that " * * * heavy duty pavement could bridge and overcome deficiencies in the subgrade." Accordingly, heavy duty pavements with prohibitive thicknesses have been suggested for weak or poor subgrades. The second approach focuses attention on the supporting subgrade and its associated conditions. The subgrade is to be designed or, if necessary, improved so that it will support a standard pavement section believed to be economically most feasible. This latter method emphasizes the importance of subgrade support for pavements. The function of a pavement may be regarded as to provide a good riding surface, resistant to the wear of traffic and the disintegrating influence of climate, and to shield the subgrade

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and maintain its ability to support applied loads. One well-known example of this practice is the Michigan method of design for flexible pavement in which the supporting foundation is designed to support a standard pavement section depending on the traffic volume to be carried.[2] The writer has no intention in this discussion to further discuss these methods of design but merely wishes to point out that, whatever the design method may be, a properly prepared or improved subgrade to receive the load distributed from the pavement is generally highly advisable. To design a pavement bridging over a weak supporting subgrade may sometimes be desirable but in most instances is too expensive to be practical. It is generally agreed that designs should "* * * provide the greatest overall economy of pavement and subgrade, taking into consideration ultimate life and upkeep cost" and that an "* * *adequate economic design of subgrade used in conjunction with a selected pavement design to meet the requirement of loading, frequency, soil and climatic conditions" is very sound engineering practice.

Among the various measures for improving the load-carrying capacities of subgrades, perhaps the most important is that which consists of proper drainage and the protection of the subgrade from the detrimental influence of water. The strength of a subgrade material is usually measured in terms of its resistance to shear which is dependent upon two fundamental properties, namely, cohesion and internal friction. The strength of practically any soil mixture will decrease due to the penetration of moisture into the voids, causing rapid disintegration and excessive volume change which weakens the cohesion of the cohesive material and changes the mechanical arrangement of soil particles thus lowering the internal friction of the granular fraction of a soil mass. Proper drainage is therefore essential in preserving a soil in a serviceable condition, not by changing the basic character of the soil, but by maintaining its sources of shearing resistance. There are certain types of soil, however, which have low permeability and high capillarity and are not susceptible to ordinary drainage. In this case other corrective measures should be adopted. Inasmuch as granular material in itself is permeable and water drains through it readily and the removal of excess moisture is not difficult, it is often used to replace undesirable subgrade soil or to blanket weak subgrade sections. In the latter case granular material not only permits better drainage conditions below the pavement but also provides for load distribution over the less stable heavy soils.

As an example showing the effect of a well-drained, granular subgrade material on the behavior of a concrete pavement, the writer wishes to submit some data regarding pavement performance at Willow Run Airport in Michigan.[3] The airport is located in an area where an outwash or delta deposit of sand and some gravel has been laid over the clay till plain. The depth of sand and gravel deposits varies from 4 or 5 feet to as much as 30 or 40 feet. The depth to the water table had varied from very deep to close to the surface during the wet period of the year but has been substantially lowered by the subdrainage system installed when the field was built. Table I shows the soil classification of typical subgrade material by three different methods in current use. It may be noted that the soil condition was close to ideal for airport construction.

2. "Thickness of Flexible Pavements," Current Road Problems No. 8-R, Highway Research Board, Washington, D. C., 1949, p. 15.
3. "Review of Pavement Performance at Willow Run Airport, University of Michigan," by William S. Housel, unpublished report, 1954.

Table I
Classification of Subgrade Soils
Willow Run Airport, Michigan

Method	Classification	Description
C. A. A.	E-1	Well-graded granular soil, stable even under poor drainage conditions and not subject to detrimental frost heave.
U. S. E. D.	SP	Poorly graded sand, little or no fines.
Bureau of Public Roads (Highway Research Board modification)	A-3 A-1-b	Poorly graded sands, some gravels, little or no fines.

The pavement at Willow Run Airport was built in three stages. The original field was built in 1941 and the pavement consisted of plain concrete with a 8-6-8 thickened edge section. In 1942 the first extensions were added. This pavement was also plain concrete but was somewhat heavier, having a 10-7-10 thickened edge section. Additional extensions were made in 1943 and this pavement too was a plain 8-6-8 thickened edge section. In 1944 the existing airport pavement installations were evaluated and the operating limit which was generally used to forecast the useful life of the runways or pavement areas was established. The flexural test results of test beams from all three construction projects showed that the modulus of rupture of the concrete in the 1941 construction was 945 pounds per square inch, in the 1942 construction 825 pounds per square inch, and in the 1943 construction 773 pounds per square inch. Under the rating system of the U. S. Engineer Office of the War Department, the gross plane weight for "capacity operation," which was based upon the maximum traffic that could possibly operate on an airfield for a period of approximately 20 years, was 52,000 pounds for runways and 41,600 pounds for the field. Under "limited operation," which was defined in general terms as a few operations a day for a period of 20 years (about 10 per cent of "capacity operation") or the maximum traffic that could possibly operate for a period of 2 to 4 years, the rating was 100,000 pounds for the runways and 80,000 pounds for the field. The minimum figure given for the field was controlled by the taxiways and aprons of the 1943 construction.

Data on the traffic and operations at Willow Run Airport have shown that the commercial airlines operating supply 80% of the aircraft movements at the field, military planes 4%, and civil aircraft 16%. According to the studies made by Professor Housel of the University of Michigan:

"As of 1953 the gross weight of commercial planes using the field varied from 26,200 pounds for the lightest plane, a DC-3, to 132,000 pounds for the heaviest plane, a Stratocruiser, and the total airline traffic amounted to 135 scheduled operations. From analysis of the scheduled operations

about 5% of the traffic exceeds the minimum field ratings by more than 200% and about 15% of the traffic is equal to or less than the field rating. As compared to the capacity for limited operations approximately 20% of the loads are greater than the limited capacity of 80,000 pounds, and approximately 5% of the traffic exceeds the limited operating capacity by approximately 65%."[4]

From these figures it is obvious that the pavement in the airfield has been subjected to traffic and loading conditions far exceeding the nominal measures of operating capacity, however, as of the end of 1953, all of the pavement, as far as the serviceability was concerned, was in a relatively good state of preservation. This is especially indicated by the 1941 pavement built on good subgrades. In this case, the crackings of the pavement which were more or less indications of the pavement performance were almost negligible and consisted largely of single transverse cracks near the center of a slab of 25 feet in length and did not constitute serious structural failure. The excellent performance of the pavement seems to be attributed largely to the excellent subgrade conditions including exceptionally stable soils and perfect drainage conditions with no necessity for providing for frost action. The evidence further indicates that a well constructed plain concrete pavement of 8-6-8 thickened edge section may be able to carry, without serious damage, heavy wheel loads and high intensity of traffic far in excess of those for which the pavement has been designed or rated under current practice, provided the pavement has been constructed on subgrades of high supporting capacity. It should be mentioned, however, that there were some critical areas where imperfections in the original construction combined with heavy loading and concentration of traffic has produced progressive deterioration. It is nevertheless believed that the damage would have been even more serious under less favorable subgrade conditions.

As mentioned by Mr. Noble, the necessity for good drainage practice and adequate subgrade support was indeed recognized by engineers more than 100 years ago. It was stated by John L. McAdam, Esq., the "Colossus of Roads," in a report to the President of the Board of Agriculture reprinted in 1824 in his book "Remarks on the Present System of Road Making" regarding the making and repairing roads in Great Britain that:

> "* * *it is the native soil which really supports the weight of traffic:. . . while it is preserved in a dry state, it will carry any weight without sinking, . . .it does in fact carry the road and the carriages also; . . .this native soil must previously be made quite dry, and a covering impenetrable to rain, must then be placed over it, to preserve it in that state."[5]

Although tremendous progress has been made in the field of highway and airport engineering since the days of McAdam, it is interesting to note that this basic principle is still of great value to the construction of highways and airports of the present day just as it was so recognized by road engineers more than 100 years ago.

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4. Ibid. p. 11.
5. "Remarks on the Present System of Road Making," by John Loudon McAdam; Longman, Hurst, Rees, Orme, Brown & Green, Paternoster Row, London, 1824, p. 46-47.

Discussion of
"STRUCTURAL SUCCESS OR FAILURE?"

by Jacob Feld
(Proc. Paper 632)

GLENN B. WOODRUFF,[1] M. ASCE.—"Most of the troubles and failures are wrapped in professional 'bees wax' and then carefully buried where the profession cannot learn from them." This statement, by Dr. N. A. Bowers, M. ASCE, reinforces the author's proposal for a joint committee through whose efforts the lessons which may be derived from such "incidents" may be made available.

Except for a few major failures, engineering literature records only success. However, even with the successes, it is far too common that "incidents," resulting from faulty design or lack of competent supervision of construction, arise. The number of such "incidents" would be reduced if designers and supervisors of construction had the facts as to the nature and cause thereof.

Many of these incidents arise from failure, during construction, to follow the plans and specifications. It is most desirable and should be the general practice that designers insist, as the author proposes, that their assignment include control of performance.

BRYANT MATHER.[2]—More careful consideration and more general reporting of the factors involved when the actual departs from the theoretical in structures is certainly desirable. In the fourth paragraph before the end of his paper, the author makes reference to "steel rectangular tanks for fuel oil storage failed completely during a very cold day," shown in Fig. 9, captioned "Collapsed steel tank by air pressure." The "Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures" presented in 1953 under the sponsorship of the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals"[3] includes a number of accounts of failures of structures, including oil tanks, in cold weather. Rear Admiral K. K. Cowart discusses and illustrates brittle fracture of an oil tank in December 1943; the atmospheric temperature was 12 F and dropping (STP 158, pp. 7-8). Prof. M. E. Shank describes 64 structural failures between 1879 and the date of his report, including those of oil storage tanks at Ponca City, Oklahoma at 6 am, December 19, 1925; eight in the South and Midwest, January 1918, November 1924, January 25, 1929, December 19, 1929, February 8, 1933; five in Russia, December 12-14, 1947; one in the Midwest, 7:31 am, February 2, 1947; one in Normandy, France,

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2. Civ. Engr. (Concrete Research), Concrete Div., Waterways Experiment Station, Corps of Engrs., U. S. Army, Jackson, Miss.
3. American Society for Testing Materials, Special Technical Publication No. 158, 1954.

winter 1950 and 1951; two in Fawley, England, February 12 and March 7, 1952; and three in Europe in 1952. (STP 158, pp. 45-108). These accounts, it is believed, indicate substantial progress toward the objective the author is advocating and also suggest a possible additional factor in the occurrence he mentions.

The remark in the first paragraph of the paper that "usually it is a combination of conditions, mistakes, even dishonest performance, but not a single item by itself can be picked as the sole and only cause of failure. Yet each in a way is what may be the responsible straw that broke the camel's back," deserves emphasis. The writer has, for some time, been referring to the "straw-that-broke-the-camel's-back theory" of the failure of concrete always to provide the service expected of it. Here, in the case of a construction material, we often have the same situation that the author speaks of with regard to structures: failure without a single item being properly picked as the sole and only cause of failure. After careful analysis of a case of concrete failure, it is sometimes necessary to conclude that the failure might have been avoided if (a) the aggregates had been of a little better quality, or (b) the cement had been of a little better quality, or (c) the water-cement ratio had been a little lower, or (d) the spacing of the entrained air voids had been a little closer, or (e) the consolidation had been a little more thorough, or (f) the curing had been a little more effective. It is thus not surprising that the reference to the straw that broke the camel's back strikes a responsive chord.

It is suggested that the author's proposal be extended to include the accumulation of estimates of the relative proportions of structures of various types and construction materials of various classes that give service in the way expected of them and the proportions that do not. Often we are so preoccupied with pathological examples that we fail to appreciate the abundance or learn the properties of the non-pathological cases. It is also suggested that for each case in which several factors are cited as straws, any one of which may be selected as the camel's back-breaker, equal attention be given to other cases in which these same factors are present but the camel is still staggering on apparently unaware that he shouldn't be. The study of "bad" structures and materials that are giving "surprisingly good" service may prove as fruitful as the study of "good" structures and materials that have given "surprisingly poor" service.

THOMAS C. KAVANAGH,[4] M. ASCE.—A fairly thorough historical summary and analysis of structural failures which have occurred in the field of bridge engineering has recently been published in Switzerland.(1) The theme of that summary, and indeed of the present author's paper, is the oft-quoted remark of Dr. David B. Steinman,(2) "Engineering failures are the price we pay for progress. If we profit from the experience, these failures will not have been in vain."

One of the noteworthy findings of the above report is that aside from bridge failures due to war or to unusually high water, one of the most frequent causes of failure is the test loading condition imposed by many foreign specifications before a bridge is accepted for traffic. This raises the serious implication that such test loadings ought to be required more frequently.

Scattered records of bridge failures exist, but an idea of what can be done is given by the most comprehensive study in the U. S. to date, namely, the statistical summary by C. F. Stowell(3) of 502 failures occurring in the years

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4. Partner, Praeger-Kavanagh, Engrs., New York City.

1878 to 1895, and published in the RAILROAD GAZETTE. The need for a more coordinated and systematic review of failures is indeed one of the important areas of structural research, which has been largely neglected in the past.

REFERENCES

1. "Bridge Failures and Lessons Learned from Them," (Brueckeneinstuerze und Ihre Lehren), published in German by Conrad Stamm, Mitteilungen Aus Dem Institut Für Baustatik, (1950) No. 24, Verlag Leemann, Zurich.

2. Civil Engineering, 15 (1945), No. 10, p. 472.

3. Reviewed in Schweizerishe Bau Zeitung, 24 (1894) p. 166 and 29 (1897) p. 6.

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